Phenomenology of Very High Multiplicity Hadron Processes

J.Manjavidze[1] *and A.Sissakian*[2]

Abstract

We discuss the possibility to suppress the nonperturbative effects if the very high multiplicity hadron final states are chosen. The theoretical uncertainties and possible experimental measurements are described.

1. Very high multiplicity (VHM) events are expected to be produced at the future experiments at BNL (STAR), Fermilab (CDF), CERN (ATLAS). Then, it is natural to expect the VHM region to give new important information, which will be complementary to the ongoing investigations and/or unavailable in other than the VHM process. The studies of the VHM region have been proposed recently in [1] and attract an increasing interest in high energy physics [2, 3, 4, 5].

In this Letter, where we briefly consider the VHM topic in whole, we particularly emphasize the related physical quantities expected to be measured with forthcoming experiments. In this sense, it is crucial to understand experimental abilities of such measurements, since the topological cross section, σ_n, is extremely small (e.g., at TeV energies, $\sigma_n \ll 10^{-7}\sigma_{tot}$, compared to the total cross section σ_{tot}, Fig.1) and could lead to certain problems.

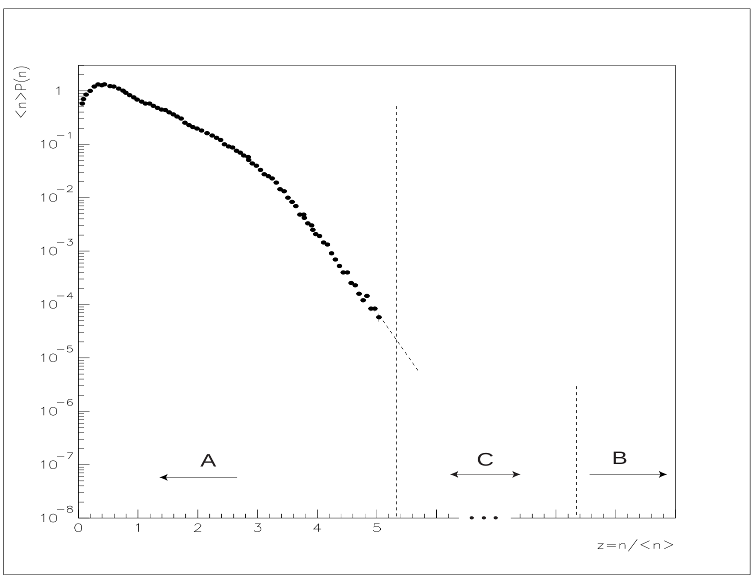

Figure 1: The KNO multiplicity distribution, $P(n) = \sigma_n/\sigma_{tot}$. The points are the E735 Tevatron data [6]. The range **A** corresponds to the multiperipheral kinematics. The range **B** corresponds to the non-interacting, ideal, gas approximation, $n \ll n_{max}$. **C** is the VHM region.

Started investigations of VHM processes, one has first of all ask a question: why the mean multiplicity in hadron processes being energy dependent as $\ln^2(s/m_\pi^2)$ is much *smaller* than the threshold multiplicity value $n_{max} = \sqrt{s}/m_\pi$ [7]? Here $\sqrt{s}$ is the c.m.s. energy and m_π is the pion mass.

[1]JINR,Dubna, Russia & Inst. of Phys., Tbilisi, Georgia. E-mail: joseph@nusun.jinr.ru
[2]JINR, Dubna, Russia. E-mail: sisakian@jinr.ru

In the present Letter, we follow the idea [1] that the multiple production process could be considered as a process of hot tea cooling in a cold environment. Then very hot tea cooling in very cold room is analogous to the VHM process. In that case, the cooling process proceeds "quickly", i.e. any process obstacled to the cooling fluctuations must be suppressed. The idea that the hadron multiple production process may consist of various mechanisms has been considered in [8].

In the QCD parton picture [9] the "fastness" of a process means that parton decay must prevail over its dissipation from an interaction zone. This is possible if the parton virtuality $|q|$ is high enough as far as the parton lifetime is $\sim 1/|q|$. As a result, the VHM process should be hard and, therefore, the forces preventing particle production (confinement) must be negligible.

Fig.2 shows the longitudinal-transverse momenta phase space domain of the VHM process. It is remarkable that the VHM domain occupies both regions, the "low-$p_{\|}$" and the "low-$p_{\perp}$" ones. Therefore, despite the fact that the VHM process is hard one can not use the Leading Logarithm Approximation (LLA) [10] to describe it [1]. To stress is that, following the LLA formalism, there are the only two domains, namely the Regge and Deep inelastic Scattering (DIS) domains, as shown in Fig.2. The corresponding cross sections may be sufficiently large and the LLA is applicable.

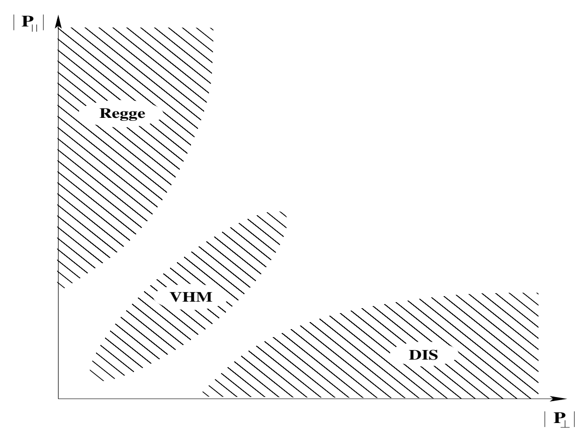

Figure 2: The longitudinal-transverse momentum phase space of inelastic hadron processes, see text.

The "low-$p_{\|}$", or "low-x" [11] in DIS, also means that VHM particles have low energies. For that reason, the hadrons are mainly resulted from the "gluing" of coloured constituents created in the hard process. Therefore, *the (soft) process of coloured parton pair production from the vacuum is negligible in the VHM domain.* This distinguishes VHM processes from other hard processes (e.g., from hadron production in $e^{+}e^{-}$-annihilations, or DIS processes). The VHM dynamics is free of the non-perturbative background.

Sec.2 argues the above conclusion, in Sec.3 the main properties of VHM dynamics are discussed and the concluding remarks are given in Sec.4.

2. The dominance of "Regge" processes stands for the "softness" of hadron dynamics [12]. This is based on the experimental observations: the mean transverse momentum of secondary particles, being energy and multiplicity independent, has a limited value, and the diffraction radius of hadron elastic scattering increases with increasing energy. Such "multiperipheral" kinematics is described by the Regge model with the *soft Pomeron* ansatz.

From the "microscopical" point of view, it means that the soft process can be roughly described by the very spatial class of the Feynman "ladder" diagrams of perturbative QCD (pQCD). This is the so-called "*BFKL Pomeron*" solution [13]. It is based on the LLA approach and assumes that the process described is sufficiently hard[3].

The both models are based on the assumption that the mean transverse momentum of produced hadrons is small. In the frame of the *soft Pomeron* approach, this constrain is hidden in the conservation laws, which are the consequence of the underlying non-Abelian gauge symmetry. In the *BFKL Pomeron* case, the LLA place a role of the constrain.

It is worse to note that the constrain restricts the production dynamics and, therefore, the produced states can not entirely cover the phase space with the same density, Fig.2. This requires the constrain to be suppressed in order to lead to the VHM final states. Remembering that the constrains are the consequence of the long-range connections among interacting degrees of freedom, this also points out that the VHM process must be the hard process.

The VHM scenario discussed realizes if (i) the hard processes has place in the VHM region and if (ii) the hard process ensures the "fast" hadron production.

The formal proof of the item (i) contains the following steps [1, 14]. First, it can be shown that if the final-state interactions are excluded, then the *soft* process only satisfies the following asymptotics:

$$\sigma_n^s < O(e^{-n}),$$

i.e. the "soft" topological cross section σ_n^s falls down faster than any power of $\exp\{-n\}$. The reason is just the softness of the process. On the other hand, the *hard* process leads to the following asymptotic estimate:

$$\sigma_n^h = O(e^{-n}).$$

Consequently, one always finds such energy $\sqrt{s}$ and multiplicity n that

$$\sigma_n^h \gg \sigma_n^s \text{ for } n \ll \sqrt{s}/m_\pi.$$

This proves the item (i).

The qualitative argument for the statement (ii) follows from the Ehrenfest-Kac model [15] of the irreversibility phenomenon[4]. It shows that if the initial state is far from the final one, then the system undergoes to equilibrium *in the fastest way* [5]. The result of the computer modelling of "particle production" within discussed model, Fig.3, confirms this. Indeed, as it is seen there are no fluctuations at early stage of the process: number of the "produced particles" is proportional to t, up to $t \simeq 1000$.

The formal proof of the statement (ii) can be obtained from the KNO-scaling of the multiplicity distribution in pQCD jets [1]. Introducing the quantity

$$\mu(n,s) = -\frac{1}{n}\ln\left\{\frac{\sigma_n(s)}{\sigma_{tot}(s)},\right\} \tag{1}$$

one finds at the mass M of a jet,

$$\mu_1(n,M) = \frac{a}{\bar{n}_j(M^2)} + O(1/n).$$

[3]The point is that this Regge-like theory depends on the phenomenological energy scale parameter s_0 and, therefore, its range of application may be chosen arbitrary.

[4]The Ehrenfest-Kac model considers two box a and b and $2N$ *numbered* balls. One may assume that the "far from the equilibrium" initial state presents the situation when all $2N$ balls are e.g., in the box a and in the equilibrium each box contains N balls. Then, choosing *randomly* the number of balls, one should take the corresponding ball from the box and put it into the other one. At the following step, the number of a ball will be again randomly chosen, and the corresponding ball should be put into the other box, and so on. One may measure the time t in the units of the ball shifting time. Then, the number of the "produced particles" in the box b measures the trend to equilibrium. In this equilibrium state, $N_a = N_b$ (Fig3).

[5]This phenomenon was not mentioned in the known publications concerning the Ehrenfest-Kac model.

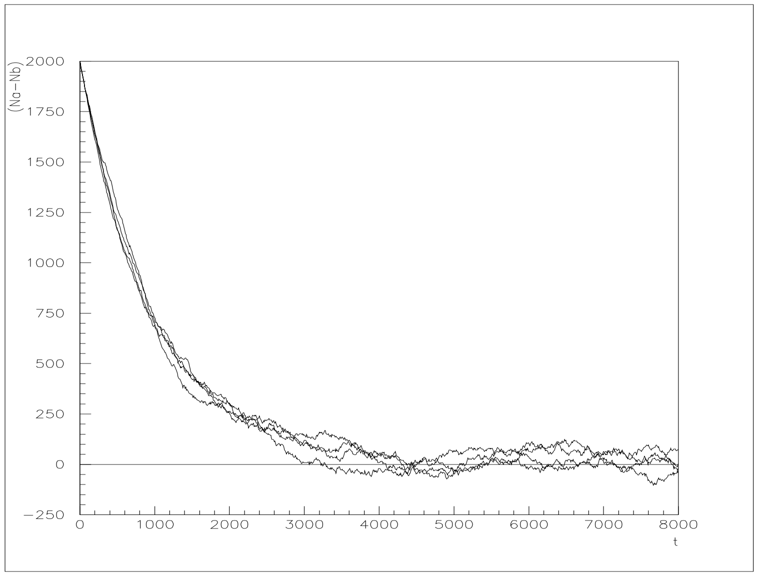

Figure 3: The Ehrenfest-Kac model simulation for random ball shifting from the a box to the b box. Initially the number of balls is N_a=2000 and N_b=0, while in the equilibrium, $N_a - N_b = 0$. Four simulations are displayed.

Here $a > 0$ and $\bar{n}_j(M^2)$ is the mean hadron multiplicity in a QCD jet, $\ln \bar{n}_j(M^2) \sim \{\ln(M^2/\Lambda^2)\}^{1/2}$. The two-jet contribution at the same energy M reads as

$$\mu_2(n, M) = \frac{a}{\bar{n}_j(s/4)} + O(1/n) > \mu_1(n, s),$$

where the energy conservation law is taken into account. Therefore, the asymptotics over n is defined by the events with the lowest numbers of pQCD jets.

This confirms the statement (ii) since just the jet mechanism of particle production is known to be the fastest one. Moreover, we conclude that the number of the jets decreases with increasing total multiplicity n and, thus, the heavier jets are produced in the VHM region. However, one has to note that this conclusion is based on the LLA and, therefore, we consider it just as a qualitative prediction.

3. From the above, one concludes that the VHM process is a hard process. In this case, the process of incident energy dissipation evolves *freely*, i.e. without the influence of the "hidden constrains". This is the important observation because it allows to assume that in such conditions the of final state distribution trends to the "equilibrium".

Let us remind some statistical properties of the maximally constrained systems, also called the "exactly integrable systems". It is known that if the system has $2N$ degrees of freedom and holds N constrains (first integrals in involution) then no thermalization occurs in such a system. The first observation of this phenomenon belongs to Fermi, Pasta and Ulam [1, 17]. On the other hand, it is evident that the system without any constrains should drift to the equilibrium.

The hadron dynamics hides definite number of constrains, which is not enough to completely suppress particle production, i.e. the thermalization process. This conclusion follows from the existence of large multiplicity fluctuations, see Fig.1. Nevertheless, the constrains occur and the mean multiplicity is reasonably small $\bar{n}(s) \ll n_{max}$.

To stress is that the term "equilibrium" is understood here as the absence of any macroscopic correlations among the extensive parameters of a system. For example, the absence of energy correlations implies the thermal equilibrium. Then, one can obtain the experimental condition, which reflects the "equilibrium phenomena" [1, 18]. It has been shown that the condition

$$R_l(n,s) = \frac{|K_l(n,s)|^{2/l}}{|K_2(n,s)|} < 1, \quad l = 3, 4, ..., \tag{2}$$

is the necessary and sufficient one to reach thermalization. Here $K_l(n,s)$ are the l-point energy correlators in the n-particle system, $l < n$. To note is that (2) reminds the "correlation relaxation condition" of Bogolyubov [19].

The tendency of the system to reach the equilibrium is considered as the dynamical effect, when the (symmetry) constrains are switched off, and for that reason the system may drift to the equilibrium state.

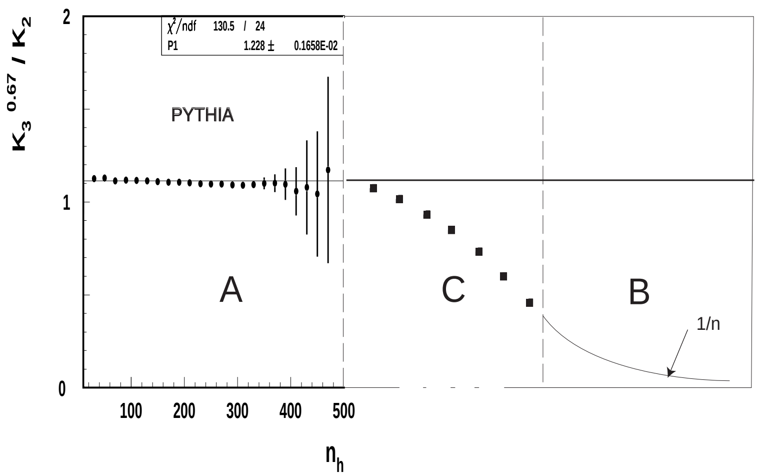

Figure 4: The ratio $R_3(n,s) = |K_3|^{2/3}(n,s)/|K_2(n,s)|$ of the energy correlators vs. multiplicity. The PYTHIA prediction is given for the **A** domain (see Fig.1). Domain **B** corresponds to the "non-interacting gas" approximation.

Fig.4 shows the result of Monte Carlo PYTHIA event generator [21] simulation of the ratio $R(n,s)$ for the domain **A** in Fig.1. The absence of the thermalization process is natural if one notes that PYTHIA resembles the Regge model. At the same time, it can be shown that in the region **B** the system without fail reaches the thermal equilibrium, $R(n) \sim 1/n$ in that domain.

4. We can conclude that:

(i) the VHM process allows us to investigate the hadron dynamics beyond the standard multiperipheral kinematics;

(ii) it is the hard process in sense that the influence of hidden constrains, connected with the high symmetries and the nontrivial vacuum of the Yang-Mills theory, is not important in the particle production dynamics;

(iii) the VHM process allows us to reach the thermal equilibrium, where the ordinary thermodynamical methods can be used. (This extends experimental possibilities and, therefore, is extremely important. For example, the μ-quantity introduced in (1) is the "chemical potential" if measured in the units of the mean energy of produced particles [1]);

(iv) the VHM domain seems to be one of the mostly interesting regions to investigate the collective phenomena, e.g. phase transitions. (To note is that the VHM final state is a "cold" one).

To note is that the production dynamics of VHM states might be well enough described by pQCD, but the logarithmic accuracy seems to be not enough. This is a main theoretical problem and to this end a more accurate perturbation theory, described in [20], has been formulated.

At the end, let us add that, as it follows from the above conclusion, the VHM process leads to the *dense*, *cold* and *equilibrium* locally-coloured state, e.g. "cold" plasma [22][6].

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References

[1] J.Manjavidze and A.Sissakian, Phys. Rep., 346 (2001) 1

[2] J.Manjavidze, Fields & Particles, 16 (1985) 101

[3] I.M.Dremin and V.A.Nechitailo, hep-ph/0207068

[4] J.Manjavidze and A.Sissakian, to appear in Proceedings of the Int. Conf. on High Energy Physics (Amsterdam, 24-31 July, 2002).

[5] S.Eliseev, L.Jenkovsky, G.Kozlov, B.Struminsky, talks at the VHM Workshops (Dubna, 2000-2002). See also contributions to the VHM Session of the XXXII Intern. Symp. for Multiparticle Dynamics (Alushta, Ukraine, 7-13 Sept., 2002)

[6] T.Alexopoulos et al., Phys. Rev, D48 (1993) 984

[7] Particle Data Group, K.Hagiwara et al., Phys. Rev., D66 (2002) 0001

[8] A.N.Sissakian and L.A.Slepchenko, Preprint JINR, P2-10651, 1977; A.N.Sissakian and L.A.Slepchenko, Fizika, 10 (1978) 21

[9] Yu.L.Dokshitser, D.I.Dyakonov and S.I.Troyan, Phys. Rep., 58 (1980) 211

[10] For a review, see V.A.Khose, W.Ochs, Int. J. Mod. Phys., A12 (1997) 2949

[11] L.V.Gribov, E.M.Levin and M.G.Ryskin, Phys. Rep., C100 (1983) 1

[12] P.V.Landshoff, Nucl. Phys.,B25 (1992) 129; M.Baker and K.Ter-Martirosyan, Phys.Rep., C28 (1976) 1

[13] E.Kuraev, L.Lipatov and V.Fadin, Sov. Phys. JETP, 44 (1976) 443; JETP, 71 (1976) 840; L.Lipatov, Sov.J. Nucl. Phys., 20 (1975) 94; V.Gribov and L.Lipatov, Sov.J. Nucl. Phys., 15 (1972) 438, 675; G.Altarelli and G.Parisi, Nucl. Phys., B126 (1977) 298;I.V.Andreev, Chromodynamics and Hard Processes at High Energies (Nauka, Moscow, 1981)

[14] J.Manjavidze, El. Part. At. Nucl., 16 (1985) 101

[15] M.Kac, *Probability and Related Topics* (Intersciens Publ., London, New York, 1957)

[16] J.Manjavidze and A.Sissakian, JINR Rap. Comm., 5/31 (1988) 5; *ibid.*, 2/288 (1988) 13

[17] A.F.Andreev, JETP, 45 (1963) 2064

[18] J.Manjavidze, El. Part. At. Nucl., 30 (1999) 124

[19] N.N.Bogolyubov, stadies in Statistical Mechanics (North-Holland, Amsterdam, 1962)

[20] J.Manjavidze, Journ. Math. Phys., 41 (2000) 5710; J.Manjavidze and A.Sissakian, Theor. Math. Phys., 123 (2000) 776; J.Manjavidze and A.Sissakian, J. Math. Phys., 42 (2001) 641; *ibid.*, 42 (2001) 4158; J.Manjavidze and A.Sissakian, Theor. Math. Phys., 130 (2002) #2

[21] T.Sjöstrand et al., Comp. Phys. Com., 135 (2001) 238

[22] L.Van Hove, Ann. Phys. (N.Y.) 192 (1989) 66

[6] It is hard to imagine the coloured state to form the QCD plasma one if the former is "hot". In this case the kinetic motion would rapidly separate the charges and this must lead to the strong polarization of the vacuum. This effect is absent in the QED plasma.